Topological Randomness and Number of Edges Predict Modular Structure in Functional Brain Networks.

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In a recent paper, Bassett et al. (2011) have analyzed the static and dynamic organization of functional brain networks in humans. We here focus on the first claim made in this paper, which states that the static modular structure of such networks is nested with respect to time. Bassett et al. (2011) argue that this graded structure underlines a "multiscale modular structure".

In this letter, however, we show that such a relationship is substantially mediated by an increase in the random variation of the correlation coefficients computed at different time scales. In page 8 of their Supplementary Information, Bassett et al. (2011) report that the size of the mean correlation diminishes with the size of the time window. Such a decrease in overall correlation will generally have two effects: (i) networks' topologies will become increasingly more random and (ii) the number of significant edges will decrease. In this letter, we use synthetic data sets to show that these two phenomena are likely to be associated with a higher number of modules, thereby potentially explaining the apparent multiscale modular structure described by Bassett et al. (2011). Our simulations are based on the unweighted unsigned version of the modularity algorithm of Clauset et al. (2004), but may be extrapolated to weighted signed adjacency matrices. In panel (A) of figure 1, we have generated 1,000 unweighted lattices based on 112 vertices as in Bassett et al. (2011). By randomly rewiring the edges of these lattices, we show that the number of modules in these networks tends to increase with the level of topological randomness in these graphs. For panels (B) to (D), we have generated two sets of unweighted networks, characterized by a random and a regular topology, respectively, with different number of edges. These simulations were repeated 1,000 times for each type of graph for each number of edges. For both types of networks, the number of modules in these graphs tended to decrease as new edges were added. Collectively, although these data simulations do not entirely rule out the possibility of a temporally nested modular structure in the human brain, they nonetheless cast doubts on the possibility of detecting such a temporal organization by reducing the size of the sampling window.

Note that our discussion, in this letter, has solely been concerned with *static* brain networks. Thus, this critique does not call into question the two other main conclusions of the paper published by Bassett et al. (2011), which pertain to the *dynamic* properties of these brain networks.

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References

Bassett, D.S., Wymbs, N.F., Porter, M.A., Mucha, P.J., Carlson, J.M., and Grafton, S.T. (2011). Dynamic reconfiguration of human brain networks during learning. *Proceedings of the National Academy of Sciences*, **108**(18), 7641–7646.

Clauset, A., Newman, M.E.J., and Moore, C. (2004). Finding community structure in very large networks. *Phys. Rev. E*, **70**(6), 066111.

Kamada, T. and Kawai, S. (1989). An algorithm for drawing general undirected graphs. *Information Processing Letters*, **31(1)**, 7–15.

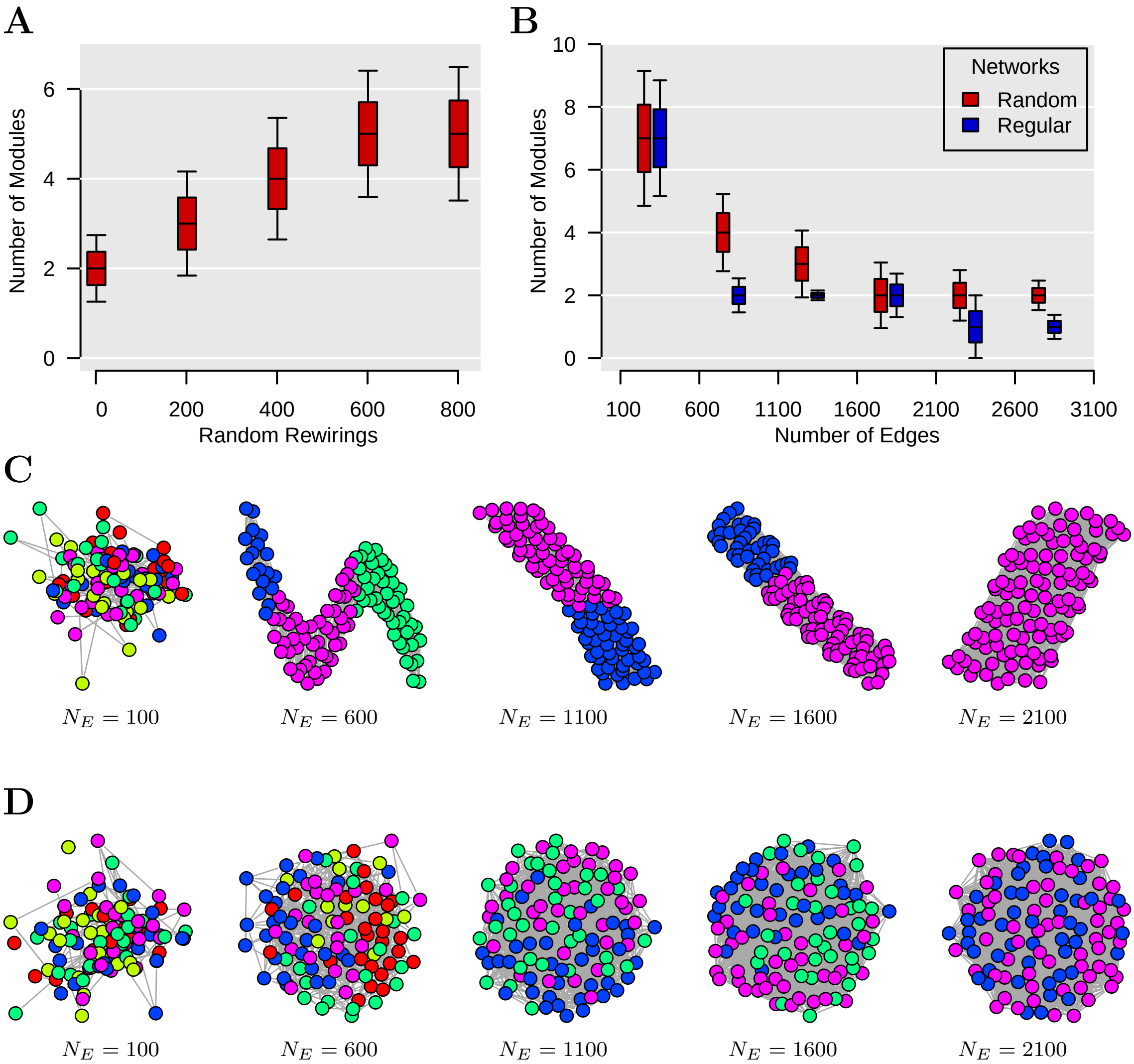

Figure 1. Topological randomness and number of edges predict number of modules. (A) Relationship between the number of random rewirings of a regular lattice and the number of modules in such a network. Here, the number of edges is kept constant throughout all rewirings. (B) Relationship between the number of edges in a network and its number of modules for both regular (i.e. lattice) and random graphs. This shows that the number of modules tends to decrease as more edges are added to both types of networks. (C-D) Modular structures of regular (C) and random (D) networks for different number of edges, N_E. These networks are represented using the algorithm of Kamada and Kawai (1989) with different colors representing different modules. In all simulations, the number of vertices is $N_V = 112$.